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Residual stress analysis of fixed retainer wires after in-vitro loading: can mastication-induced stresses produce an unfavorable effect

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Running title: Residual stresses of fixed retainers

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Abstract

The aim of the present study was to compare four different types of fixed canine-to-canine retainer regarding the maximum and residual force system generated on a canine during the intrusive in-vitro loading of the rest of the anterior teeth. Retainers constructed from Ortho-FlexTech gold chain 0.038 x 0.016-inch, Tru-Chrome® 7-strand twisted 0.027-inch steel wire, Wildcat 0.0175-inch and 0.0215-inch 3-strand twistflex steel wire were bonded on the anterior teeth of an acrylic resin model, installed in the Orthodontic Measurement and Simulation System. The force system on the canine was recorded during the loading of the anterior teeth as well as the residual force system at the same tooth after the unloading. During maximum loading, the gold chain exerted the lowest and the 0.0215-inch archwire the highest force and moment magnitude. Residual forces and moments were exerted on the canine after the unloading in all retainer types i.e. the evaluated fixed retainers were not passive after in-vitro vertical loading. The lowest magnitude was measured in gold chain retainers and the highest in cases of the high formable/low yield strength 0.027-inch archwire. This fact may explain the unexpected movements of teeth bonded on fixed retainers detected long-term in-vivo.

Key words: fixed retainer; plastic deformation; unexpected tooth movement

Abbreviations: OMSS, Orthodontic Measurement and Simulation System

Introduction

After cessation of the active orthodontic treatment, retention of the treatment result is necessary in order to prevent relapse of the malocclusion. Fixed retention, i.e. the bonding of an archwire piece on two or more teeth prone to relapse, is a rather unavoidable procedure in that phase, at least for specific malocclusions or specific population groups. According to a conservative approach, if maximum stability is required, fixed canine-to-canine retainers combined with removable retention appliances in both arches should be used until the patients reach their late twenties [1], since successful treatment maintenance only with bonded retainers cannot be achieved in the long-term [2-6]. The increase of irregularity is strongly related to the bonding failures of the retainer [7] but in 3% to 5% of patients, unexpected posttreatment changes in the mandibular anterior teeth have been reported, on which a flexible spiral wire retainer (0.0195-inch 3-strand heat-treated) was still bonded. These changes show a specific clinical pattern and they could not be explained by the pretreatment malocclusion. More specific, torque differences between 2 adjacent incisors or increased buccal or lingual inclination and movement of a mandibular canine were observed. The exact reason for these changes is unknown. It was initially proposed that an active component of the wire due to either an elastic deflection caused by the clinician or a mechanical deformation from masticatory forces could probably cause these movements [7, 8]. Since the retainer is constructed and bonded passively across the surfaces of the teeth and these unexpected changes are not usually observed short term after debonding, it's more reasonable to consider as possible causes the wire deformation during its long term function in mouth or its inability to prevent the unexpected movements and the posttreatment tooth movement tendency [9]. The major consequence of these movements could be the thinning of the periodontium, which leads to bone thinning and dehiscences or even to fenestrated periodontal defects on the canine root (Fig. 1). Additionally, esthetic problems arise due to differences in the height of the clinical crowns and in the anteroposterior alignment of the incisal edges, as well as functional problems from improper occlusion with the antagonists.

The most commonly fixed retainers used are the thick mandibular canine-and-canine (0.030 or 0.032-inch) and the thin (0.0215-inch or thinner), flexible, spiral wire canine-to-canine retainers. As regards their mechanical properties, multistranded wires have high stored energy (modulus of resilience) when compared with solid stainless steel wires. This implies that they produce lower forces that dissipate over longer periods of time. Additionally they have high springback and low stiffness. However, high stiffness is advantageous in resisting deformation [10, 11]. Moreover, solid stainless steel wires could better resist torsion. In contrast to conventional stainless steel wires, in which spring back decreases with increasing thickness, multistrand wires have spring-back properties that are not influenced to the same extent as solid wires by the cross-section size [10]. As regards their clinical behavior, the thick canine-and-canine retainer could lead to a small increase in mandibular incisor irregularity during the retention period, however displays lower detachment rate than the thinner canine-to-canine retainer type [5, 12, 13].

The purpose of the present study was to compare four common flexible archwires used for fixed canine-to-canine retention regarding the maximum and residual intrusive forces and labiolingual moments generated on a canine during the intrusive loading of the rest of the anterior teeth.

Materials & Methods

All measurements were conducted on the Orthodontic Measurement and Simulation System (OMSS). This is a measuring system used widely in the field of orthodontic biomechanics and its set-up and applications have been described detail [14, 15]. OMSS is capable to evaluate three-dimensionally the initial force system exerted by an orthodontic appliance as well as the alterations of this force system during the simulation of the desired tooth movement. The simulation of tooth movement with the OMSS is conducted using two measuring tables comprising of a six-axis positioning table and a six-component force-torque sensor, monitored by a personal computer.

An acrylic resin model (Palavit G, Heraeus Kulzer, Hanau, Germany) of the mandibular anterior segment, with an ideal, leveled, and aligned dental arch, was used for the construction of the retainers. Fifteen retainers were constructed from each of the following wires by one of the authors: (1) Ortho-FlexTech gold chain 0.038 x 0.016-inch (Reliance, Itasca IL, Lot 310151), (2) Tru-Chrome® 7-strand twisted 5” 0.027-inch steel wire (RMO, Denver CO, Batch WO-433524), (3) Wildcat 0.0175-inch 3-strand twist-flex steel wire (GAC, Bohemia NY, lot 13-25) and (4) Wildcat 0.0215-inch 3-strand twist-flex steel wire (GAC, lot 13-16). A small hole was drilled with a bur for retention and standardization purposes, on the middle of the lingual surface of every tooth (diameter, 2 mm; depth, 2 mm; distance between the holes, 4 mm) and all the retainers were constructed on that level.

After the construction of the retainers, the resin model was split into 2 segments to consolidate the canine. An appropriate adaptor was fixed on each model segment, and both segments were mounted to the OMSS (Fig. 2). The bigger segment (consisting of the incisors and one canine) was mounted on a specialised specimen holder consisting of a spring damped telescope. The spring was adjusted and preloaded such that a displacement of the segment by 0.2 mm generated a counter force of 15 N, thus simulating the force/displacement behaviour of a tooth segment in the alveolar bone. The lesser segment (consisting of the other canine) was directly connected to one of the force-torque sensors of the OMSS via an adaptor. The initial leveled position of these segments was maintained throughout the experiment.

Each retainer was bonded on the teeth (canine to canine) by using equal amounts of light-cured composite (Transbond™ XT Light Cure Adhesive, 3M, Monrovia CA). The intercomposite distance was 4mm. During the measurement procedure, an intruding force was gradually applied on the bigger segment (consisting of the incisors and one canine) which was intruded in 0.05mm increments. When this force reached a maximum of 18N the OMSS released the load and returned in its initial position at the same incremental decrease. OMSS measured the maximum intrusive force and labiolingual moment on the lesser segment (consisting of the consolidated canine) during the load and unload of the bigger segment. Additionally, the residual force system at the end of the unloading cycle at the lesser segment was evaluated too. For the objectives of this study, only the intrusive forces and the labiolingual moments were used for the evaluations of the lingual retainers. The remaining force and moment components were adjusted to zero. Every specimen was evaluated once and all procedures were performed by one author.

Statistical analysis

All statistical tests were performed by STATA version 11.0 (STATA Corporation, College Station, TX, U.S.A.). Data are presented graphically through histograms and box-plots. Between types of wire differences are assessed through permutation based (1,000 replications) versions of Kruskal-Wallis and Mann-Whitney tests. P-values for the pairwise comparisons by type of group have been adjusted for multiple comparisons (Bonferroni correction).

Results

The intrusion force and labiolingual moment results (mean, SD) for all the wire types are shown in Table 1. Overall differences in maximum force, residual force, maximum moment and residual moment, according to the wire type, were statistically significant (global test $P<0.001$ in all cases). All pairwise comparisons between two different types of wire, in terms of maximum or residual force, were also statistically significant (all P-values were <0.05).

Average maximum moment and residual moment differed significantly between all couples of wire types that have been compared with the exception of the comparison between the 0.027-inch and 0.0215-inch wire type where results were not statistically significant (P=0.240 and P=0.282 for maximum and residual moment, respectively).

The rank of the different wire types in increasing order of maximum force and torque magnitude is as follows: gold chain (2.0 N / 7.6 Nmm), 0.027-inch (4.4 N / 13.8 Nmm), 0.0195-inch (3.8 N / 11.5 Nmm) and 0.0215-inch (4.8 N / 15.2 Nmm). Regarding the residual force and moment magnitude, the rank in increasing order is as follows: gold chain (0.1 N / 0.9 Nmm), 0.027-inch (0.8 N / 2.2 Nmm), 0.0195-inch (0.5 N / 1.3 Nmm) and 0.0215-inch (0.6 N / 1.8 Nmm). Distribution (box-plots) of maximum and residual forces and moments by wire type are depicted in Figures 3-6.

Discussion

In both types of unexpected posttreatment changes the main movement is the labiolingual rotation of the tooth. Additionally, bending of the last part of the retainer wire, supporting usually the canine, may occur. The present study evaluated the maximum and residual vertical forces and labiolingual moments on the terminal canine of a fixed canine-to-canine retainer during an intrusive load on the rest of the anterior teeth. This configuration simulated anterior biting, since the intrusive force exerted on the anterior teeth by OMSS approximated the vertical incisor bite force during mastication [16, 17]. If this force level is maintained within the elastic limits of the retainer wire/adhesive and the periodontal ligament, the tooth remains relatively stable. If it exceeds the elastic limit of the wire/adhesive, bond failure or deformation of the retainer wire may occur. The load of 18 N used in the present study, was decreased by the adaptors fixed on the model segments and transferred on the canine through the retainer wire to a different extent, according to the elastic properties of the wire. This wire between the canine and lateral incisor resembles a beam restrained at both ends and the loads could be axial, bending and torsional. The canine experienced the lowest force / moment during this loading in the case of the gold chain and the highest in the case of the 0.0215-inch 3-strand twist-flex steel wire. The 7-strand twisted 0.027-inch steel wire exerted lower forces/moments on the canine in comparison with the thinner 0.0215-inch wire.

In the instruction sheets provided by the manufacturer of the gold chain, it's stated that this material may stretch slightly allowing space to reopen. Accordingly, the use of a secondary retainer wire is advised in cases of diastemas. The low forces exerted on the canine in the case of the gold chain retainer in the present experiment justify the above mentioned statement.

The wire processing of the 0.027-inch twisted steel wire is not clear. The manufacturer claims that these retainer wires are constructed from a softer temper than archwire temper, which enables the operator to more easily form the wire into retainer appliances and that the forming of the wire work-hardens it, providing a working resiliency for retainer appliances. However, wires with a high degree of annealing are described in the literature as "dead-soft". As the degree of annealing increases, formability is progressively enhanced at the cost of yield strength [18]. After the unloading of the retainer, a residual force/moment was maintained on the canine in all evaluated configurations, a fact that implies plastic deformation of the retainer wires. The residual force systems from the twisted archwires were always higher in comparison with these exerted from the gold chain and the highest values were recorded in the case of the high formable/low yield strength 7-strand twisted 0.027-inch steel wire.

The labiolingual moment experienced by the canine from the intrusion of the rest of the anterior teeth was expected, since the intrusive force was applied labially to the canine. The magnitude of this moment on the canine may be influenced by the twist direction of the wire strands (left-handed or S-twist and right-handed or Z-twist), which could potentially favor a specific rotation. Moreover, an extrinsic moment could more easily deform the wire in the direction of straightening/untwisting. The opposite is also true: the wire could better withstand the deformation if the moment tends to twist its strands.

The optimal magnitude of a force for tipping movement of one tooth is 50-75cN [18] but for intrusion this magnitude is even lower [19]. The residual forces measured in the present experiment are capable to induce a tooth movement, however the fixed retainer allows only a minor tipping movement of the canine. There is no consensus in the orthodontic literature regarding ideal torquing moment. Most of the authors agree that 5.0 Nmm is the minimum torque required for an upper central incisor [20-23]. Under this aspect, the residual moments measured in the present experiment are not capable to induce a tooth movement. However, torque differences between 2 adjacent teeth are reported, which are possible only through a moment induced / allowed by the archwire. The vertical loads reported in the literature during biting vary intra- and inter-individually and could reach 250 N in the incisor area [24]. The lateral components of bite forces in that area in adults remain in lower levels, 20N [25]. As a result, the maximum and residual force systems of a retainer wire in clinical use may be considerably higher than these reported in this study. Moreover, a minor tipping force / labiolingual moment on the canine could have detrimental impact on the root position, since the center of rotation remains near the bonding area of the retainer wire. Additionally, in the case of the last tooth bonded on the retainer, every proximal force that is not exerted axially on the retainer wire may have lingual or buccal components and could induce a labiolingual moment as well as mesiodistal moment.

The findings of the present study suggest that the evaluated twisted archwires used as a lower canine-to-canine fixed retainer may not be passive after short- or long-term clinical use, especially the archwires with a high degree of annealing. Archwires with higher bending and torsional stiffness may be more suitable for this clinical application. Nevertheless, the unexpected movements of the anterior teeth bonded on a retainer are not found in cases of thick stainless steel canine-and-canine retainers, even at 5 years posttreatment [9].

Limitations exist within the experimental set-up used in the present study, which is a model that approximates the clinical situation where forces and moments are exerted onto the teeth. The OMSS is based on the principle of the two-tooth model and simulates only the initial tooth movement. Intraoral ageing and saliva are factors that are not taken into consideration. The mechanical properties of the periodontal ligament affect the transmission of the force system and as a result the actual force system acting on a canine bonded on a fixed retainer will probably vary. However, the residual force system described in this study correspond to the actual residual force system on a canine bonded on a fixed retainer in the clinical setting, independent of the periodontal ligament, if this canine experiences a differential (i.e. between this canine and the rest of the anterior teeth) intrusive force of the magnitude described in the Maximum Force row of Table 1.

Further laboratory investigation of heavier stranded or solid archwires used for fixed retention would expand the conclusions of this study. Another suggested area for future clinical research would be the evaluation of the effect of the twist direction of the wire strands on the unexpected movements of the teeth bonded on twisted fixed retainers.

Conclusions

The twisted archwires used as a lower canine-to-canine fixed retainer may not be passive after short- or long-term clinical use, especially the high formable/low yield strength archwires with a high degree of annealing.

Archwires with higher bending and torsional stiffness may be more suitable for this clinical application.

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Table 1. Distribution of intrusion forces (N) and labiolingual moments (Nmm) measurements by type of wire; mean (SD).

	Type of wire			
	Gold chain	**0.027**	**0.0195**	**0.0215**
Maximum Force	2.0 (0.4) a	4.4 (0.3) b	3.8 (0.3) c	4.8 (0.3) d
Residual Force	0.1 (0.1) a	0.8 (0.1) b	0.5 (0.1) c	0.6 (0.1) d
Maximum Moment	7.6 (1.5) a	13.8 (1.2) b	11.5 (1.1) c	15.2 (1.9) b
Residual Moment	0.9 (0.2) a	2.2 (0.6) b	1.3 (0.4) c	1.8 (0.4) b

*Means with the same letter are not significantly different at the 0.05 level. This apply only within each raw.

Figure legends

Figure 1. Unexpected buccal movement of the root of the lower right canine caused gingival recession, 3 years after debonding. A 0.027-inch fixed retainer, constructed from the same archwire evaluated in the present study, was still intact.

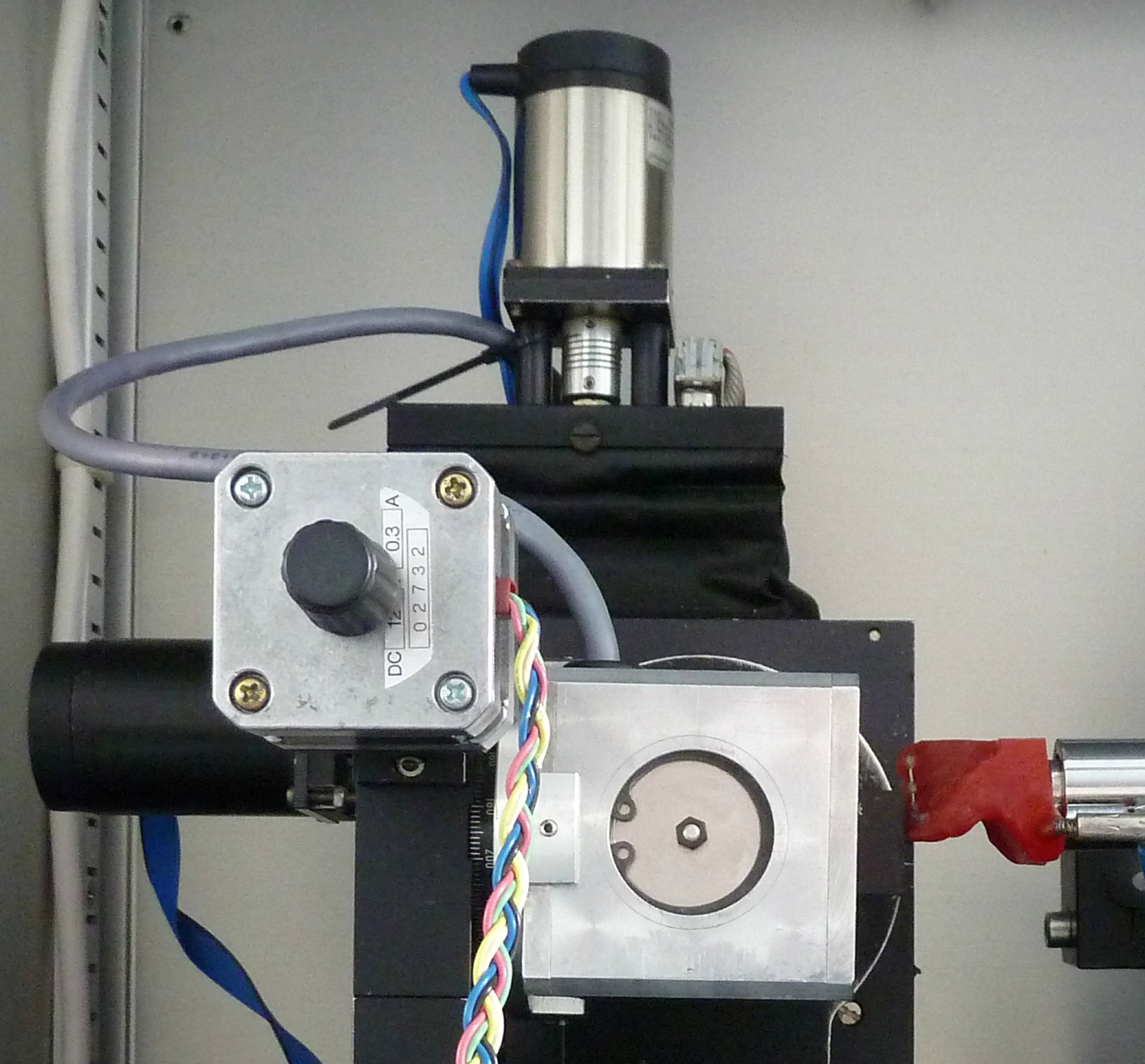
Figure 2. The resin model of the anterior segment mounted on the Orthodontic Measurement and Simulations System. On the left, one force-torque sensor is shown, used for load application on the bigger tooth segment. On the right a part of the telescope, simulating the physiological tooth mobility of the canine, is visible.

Figure 3. Distribution (box-plots) of maximum force (N) by wire type.

Figure 4. Distribution (box-plots) of residual force (N) by wire type.

Figure 5. Distribution (box-plots) of maximum moment (Nmm) by wire type.

Figure 6. Distribution (box-plots) of residual moment (Nmm) by wire type.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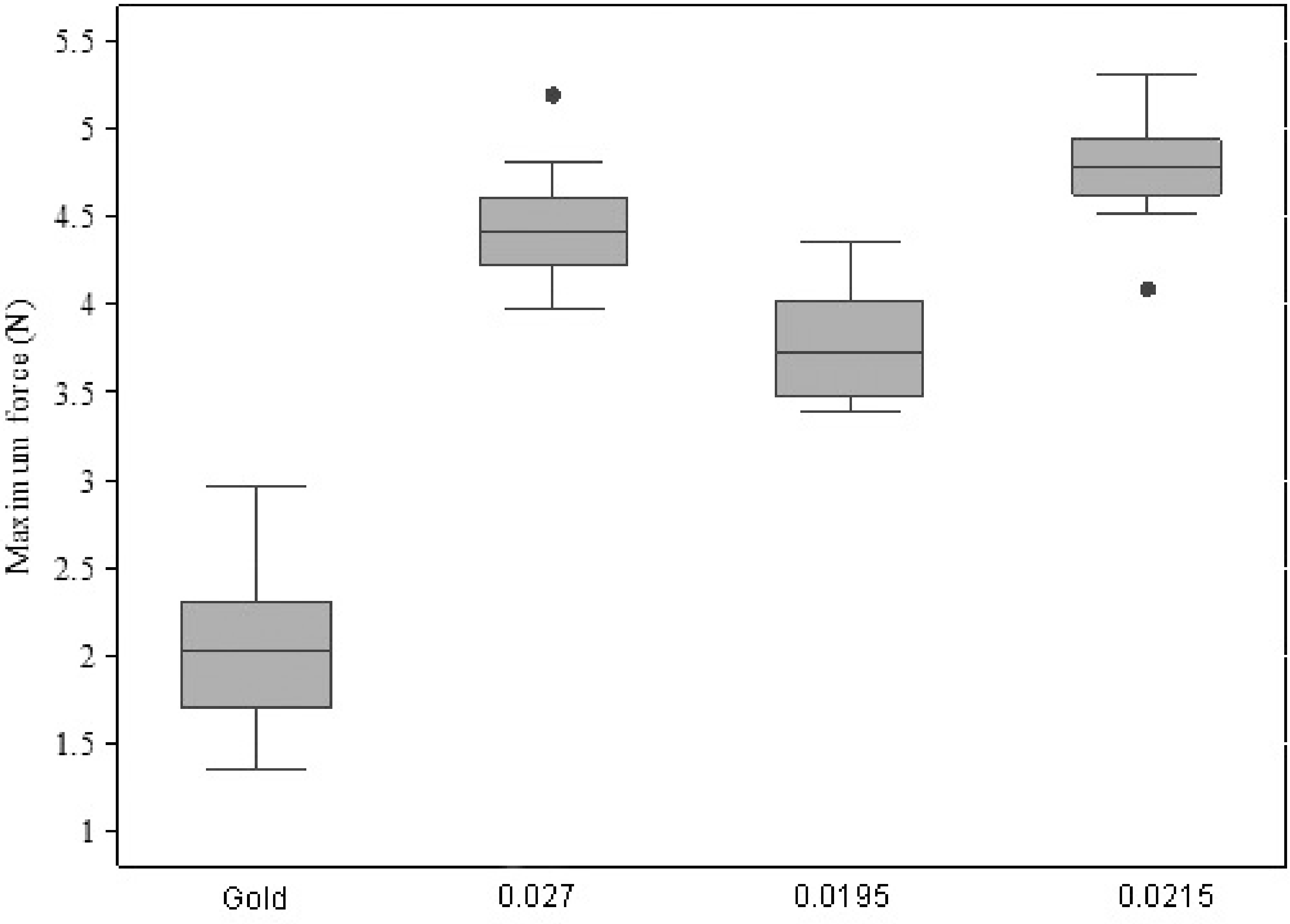
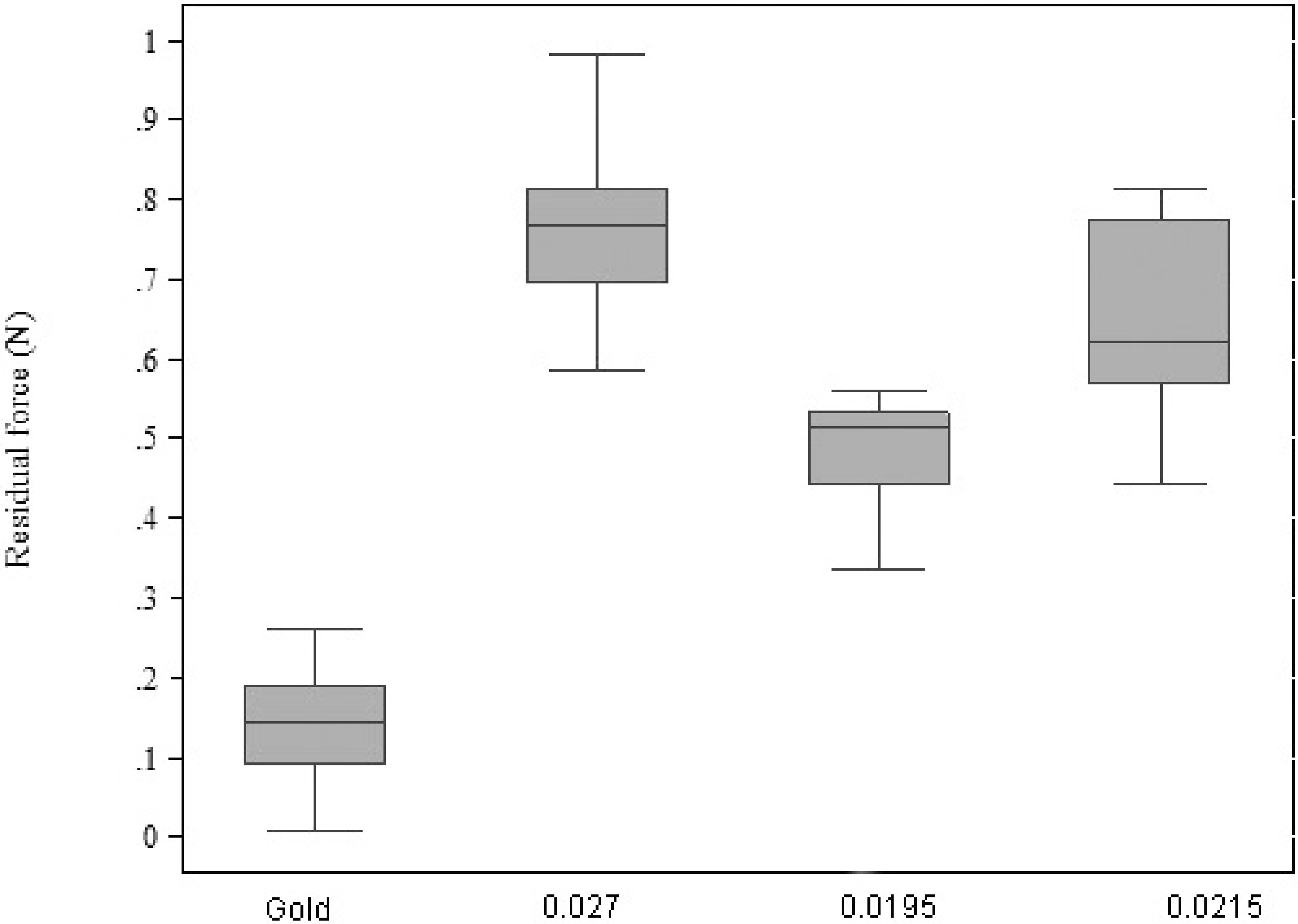
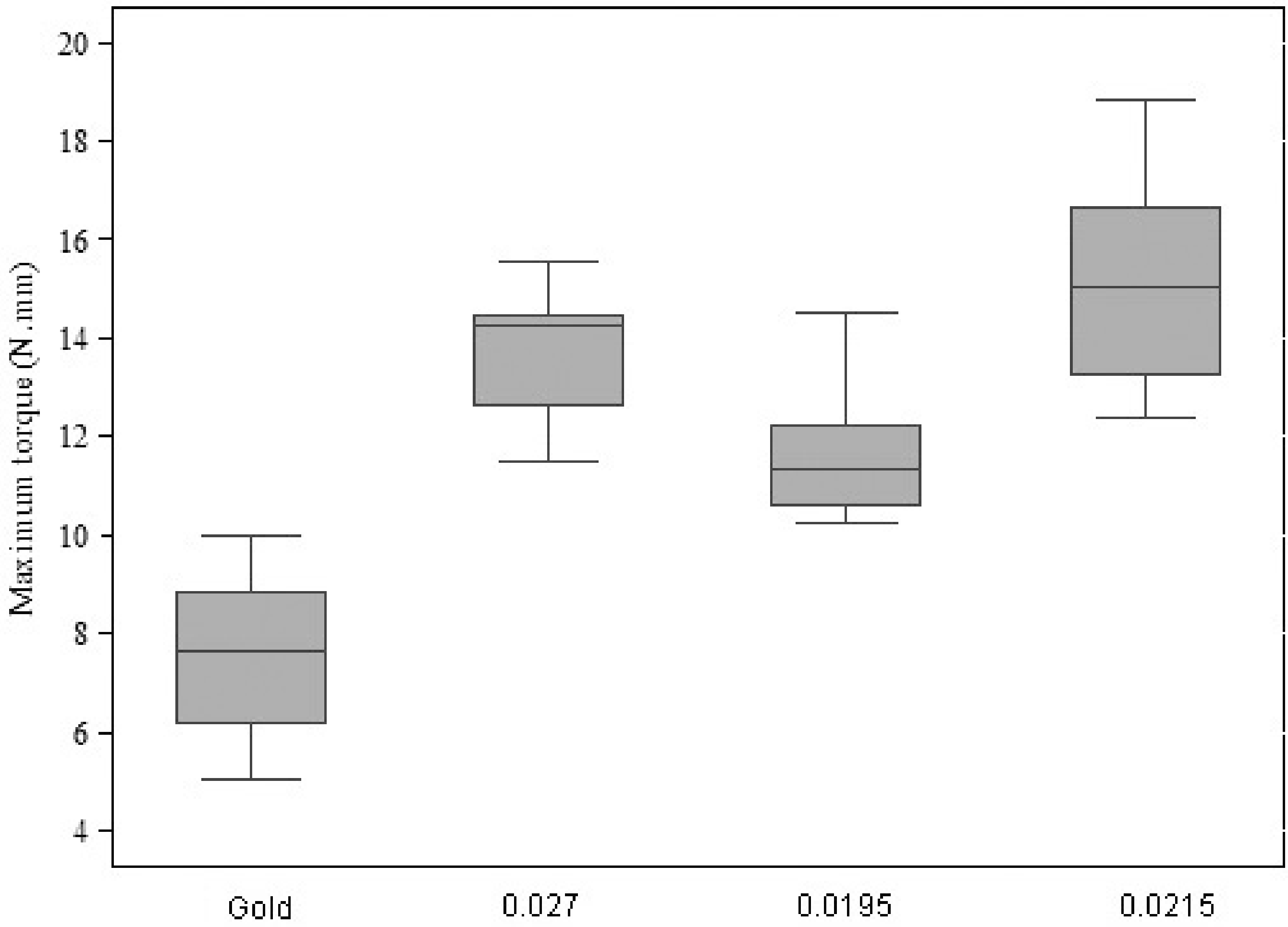
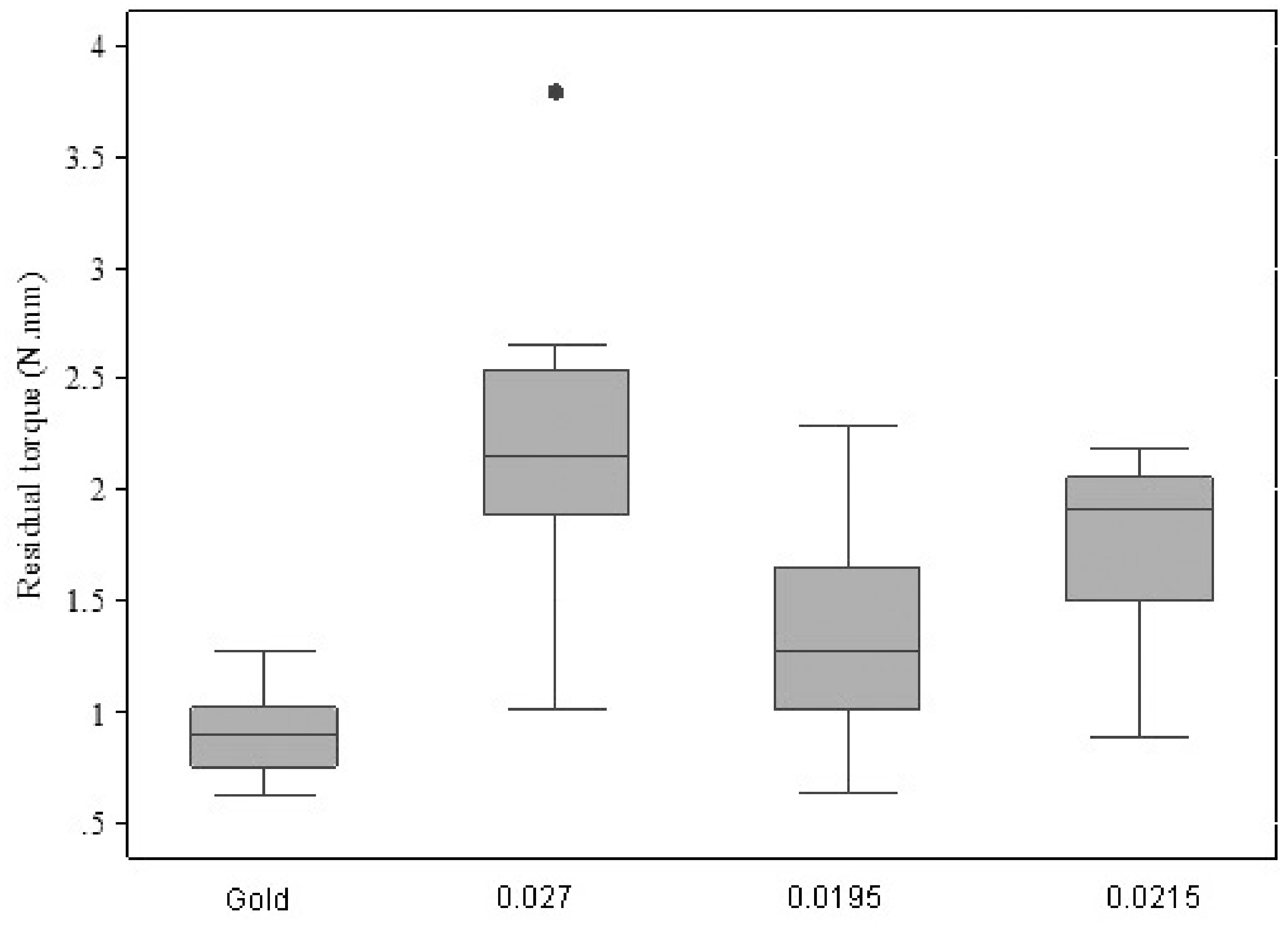


Maxim um force (N)
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
Gold
0.027
0.0195
0.0215


Residual force (N)
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
Gold
0.027
0.0195
0.0215



20
18
16
14
12
10
8
6
4
Maximum torque (N.mm)
Gold
0.027
0.0195
0.0215



Residual torque (N.mm)
4
3.5
3
2.5
2
1.5
1
.5
Gold
0.027
0.0195
0.0215